

## **Project 2: The Swinging Gripper**

24-370 Engineering Design I, Spring 2011

Assigned 16 February, First prototype due 28 March, Second prototype and report due 11 April

### **Overview:**

In this project, your team will design, fabricate, and test a robotic gripper comprised of custom and catalog components. Your team's gripper must hold a spherical object, contacting it only in specific regions. The gripper will be attached to a robot arm (provided) which will move rapidly through a circular arc. Near the attachment point on the arm, a motor-driven shaft (provided) will produce an open-loop torque when switched on. You must use this drive shaft to close your gripper on the object and hold it securely during arm motions. Don't drop the ball!

Your team must provide two fully-functional revisions of your gripper prototype for testing on the dates listed above. Both versions count! Both prototypes must meet all design and performance criteria. The only exception is dynamic performance; just one of your prototypes must successfully hold the object during rapid arm motions for full credit.

During the design process, you must use a combination of sketching and simple models, including free body diagrams and analyses in symbolic form; computer-aided design tools, including for modeling, static stress analysis and kinematic analysis of your assembly; catalog selection processes; material selection processes; and prototype manufacturing methods. You will have a small budget for purchasing catalog components. You will be required to use certain materials and manufacturing methods for some of your parts. Your team will need to fabricate and assemble your gripper on your own, unless you use funds from your budget to have parts made (within time limits). Documentation of all these steps will be required in your final report.

Diverse teams have been assigned so as to maximize the learning experience for all members. Your team will evenly divide project tasks, such that members participate in all parts of the design process evenly. Your final report will include documentation of the division of efforts. Your team will also provide anonymous self and peer evaluations.

In addition to your report and required gripper performance criteria, there are two optional challenges! The team with the lightest functional gripper assembly, including all parts, will win bonus points and a prize! Additionally, the team with the lowest-cost gripper assembly, including all costs other than team labor, will win bonus points and a prize! Teams that come close to the winning benchmarks will also win pro-rated bonus points. Prizes will be awarded based on the best of all entries from both revisions.

Please read each project description in full as they come out, so that you are not surprised by deliverables at the last moment. Please use the course email address, TA office hours, and/or Q&A sessions at the beginning of class if you have any questions about the project.

## Sketched-in specifications and constraints:

This “sketch description” is intended to give you a qualitative understanding of the design challenge, without the distracting details of quantitative data. Use this opportunity to generate conceptual sketches and perform symbolic analyses related to the design.

## Gripping geometry and kinematics:

Your team’s gripper will need to start in an open position, then close in on the spherical object and hold it firmly. The sphere will be of medium diameter compared to the useful design envelope. The sphere will be of medium to low density compared to other materials used in your design. The exterior of the sphere will have a medium coefficient of friction. The gripper attachment point will be above the sphere. Attachment may occur only in two places: at a bolt pattern in the horizontal plane on the bottom of the robot “wrist”, and on the drive shaft. The sphere cannot be supported from below by your gripper, as there is an impermissible region extending downwards from just below the hemisphere line. The gripper must also not interfere with an initial impermissible region to one side of the sphere prior to closure. The gripper must use the drive shaft to close on and hold the sphere. The drive shaft will provide an open-loop motor-driven torque of medium-low magnitude when turned on. Finally, the gripper must not extend beyond the assembly envelope (permissible region) when closed. These ideas are qualitatively shown in Figure 1.

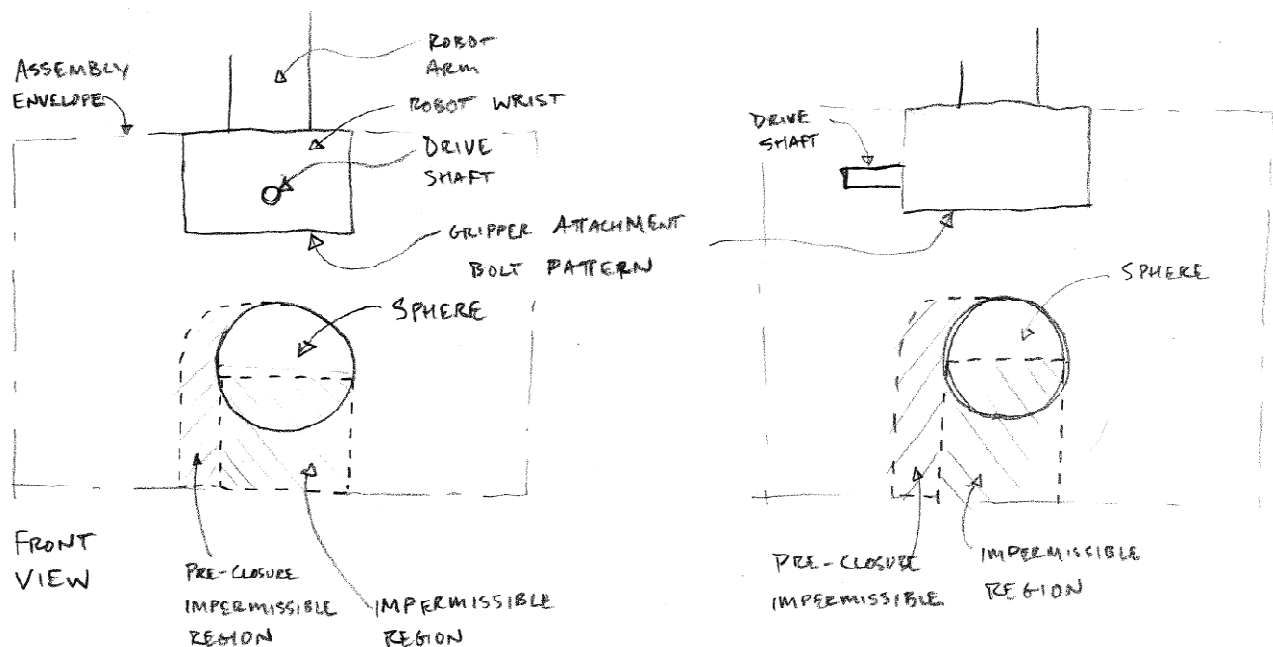


Figure 1. Gripping geometry, including possible attachment points, interference regions, and part envelope.

### Dynamic arm motions:

The gripper will be mounted to the end of a robotic arm that will swing rapidly while the sphere is held. The robot arm will be relatively long compared to the size of the gripper envelope and sphere. The robotic “shoulder” joint will be a free-rotating one-degree-of-freedom pin hinge. This joint will allow rotation within the front plane, which is the same rotational direction as the drive shaft. The robot arm will hang loosely in gravity during gripper closure. After the sphere has been gripped, the robot arm will be manually rotated to a horizontal position, and then released. This will cause dynamic accelerations to be experienced by the gripper and sphere, as long as they are moving with the arm :D These ideas are qualitatively diagrammed in Figure 2.

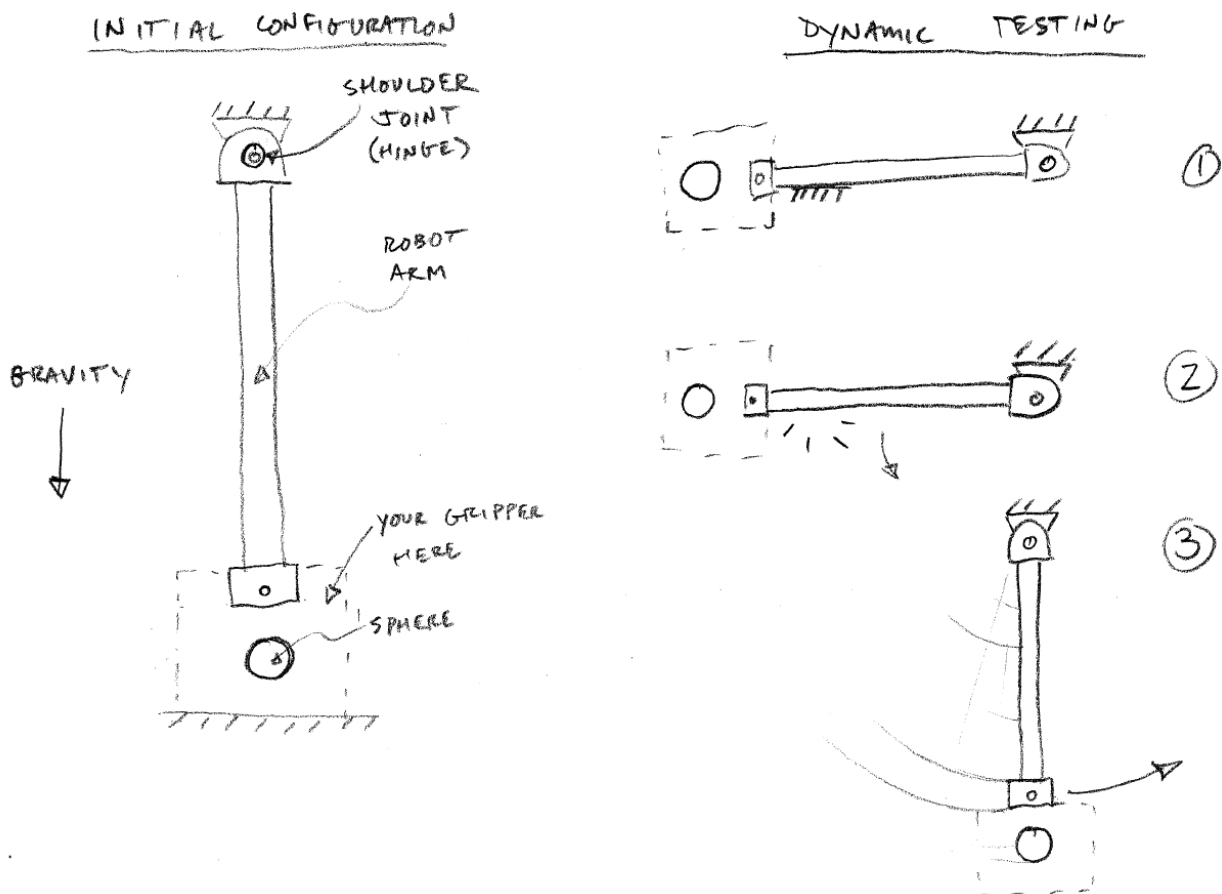


Figure 2. Dynamic robot arm motions with the gripper holding the sphere.

## Detailed Specifications and Constraints

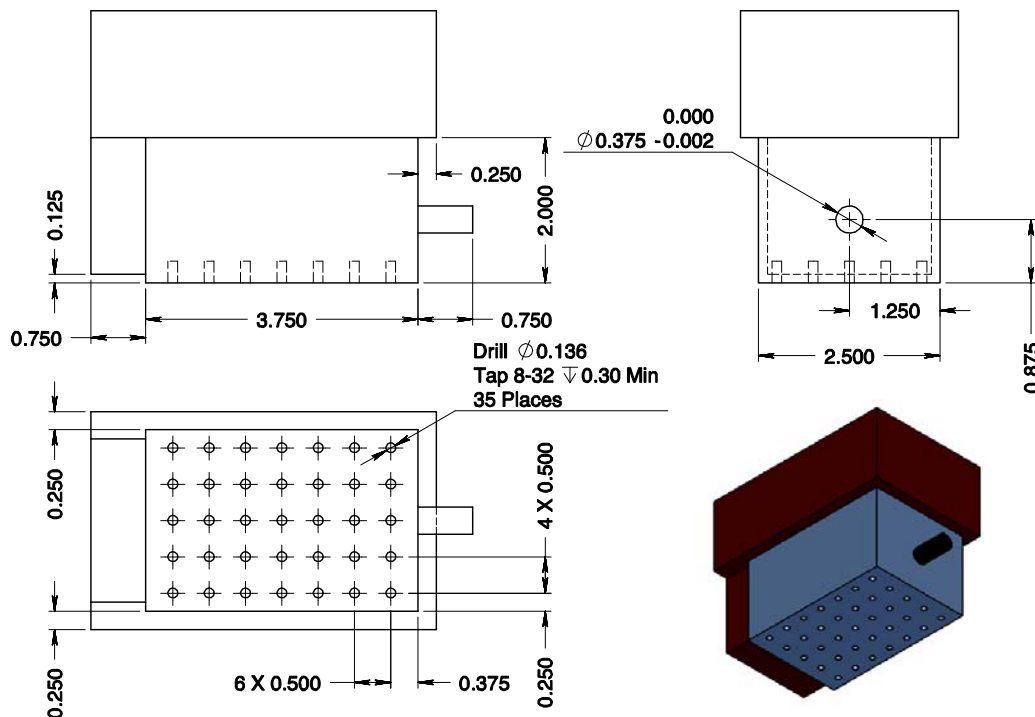
**Spherical Payload:** The outer diameter of the sphere is  $3.000 \pm 0.125$  inches and the mass is  $145 \pm 5$  g. The dry, static, steel-contacted coefficient of friction,  $\mu$ , is about 0.2. The Shore A durometer is about 70. The sphere is nonferrous and otherwise non-magnetic, with a rough semi-porous surface.

**Driving Torque:** The maximum output (stall) torque of the drive shaft is  $1.25 \pm 0.25$  N m, and the maximum (no load) speed is  $29 \text{ rad s}^{-1}$ , when the motor is switched on. Consider both the minimum and maximum possible torque when designing your gripper. You should include a factor of safety both for part strength and for holding the ball, and these might require different conservative estimates of drive torque. The torque is in a clockwise direction when looking at the shaft.

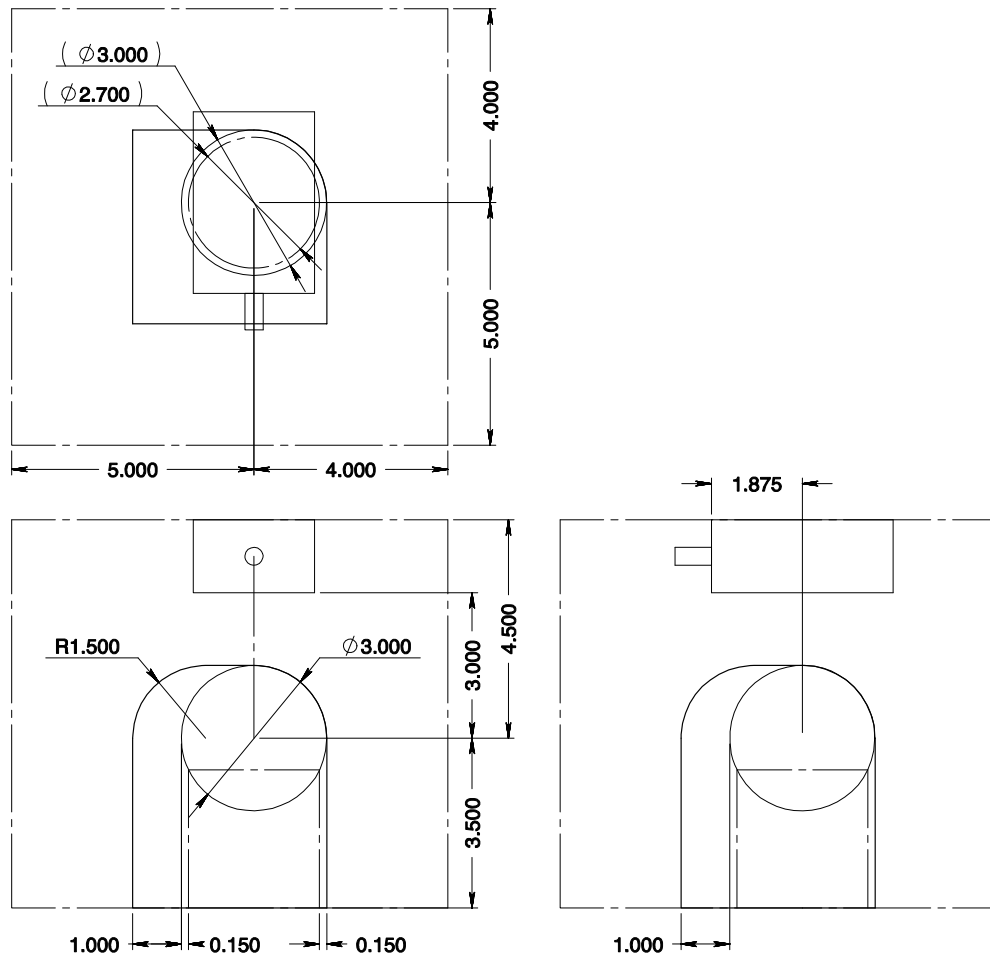
**Dynamic Arm Motions:** The arm will be released from a horizontal position. The distance between the shoulder hinge and the center of the spherical payload is approximately 28 inches, but this distance should negligibly affect your calculations.

### Gripping Geometry and Kinematics:

The details of the robotic wrist are shown in Figure 3, and details of the overall geometry are shown in Figure 4. Note that you may choose one of two possible pre-gripped non-interference regions.



**Figure 3.** Detailed robotic wrist diagram. The gripper is driven by the drive shaft (black), which will provide a torque in the clockwise direction as viewed when looking at the shaft (i.e. in the right view). The gripper attaches to the wrist using the tapped hole pattern on the bottom of the aluminum block (gray). The gripper may not interfere with the regions marked in red. The drive shaft is 0.750 inches long. A CAD model of the robotic wrist assembly is available online.



**Figure 4.** Overall geometry diagram. The spherical payload (solid circle) is centered below the gripper, with a pre-gripped non-interference region to two orthogonal sides (solid outline) and a post-gripped non-interference region below (dash-dot lines). The pre-gripped non-interference orientation may be chosen by your team to be as pictured relative to the drive shaft, or may be rotated 180° in the top view. The overall gripper envelope (dash-dot lines) creates a near cube, nearly centered on the sphere.

### Performance-based Grading

Both gripper prototypes must function in order to receive the maximum grade on your project, and at least one must hold the ball during dynamic motions of the arm. Assemblies that do not meet the geometric criteria or do not nominally function, e.g. close on the ball, will result in a loss of 5% credit at either or both stages. If neither assembly holds the ball during dynamic motions, 10% credit will be lost.

For the team whose gripper meets all requirements and successfully holds the ball during dynamic motions while comprising the lowest mass, an additional 10% bonus will be awarded. Designs that are within 33% of this winning mass will also receive a pro-rated bonus. For example, if the lowest mass were 60 g and your team's gripper weighed 70 g, your team would receive a bonus of 5%! Similarly, the team with the lowest cost functional gripper will receive a 5% bonus, with pro-rated bonuses for teams within 20% of this cost. A total of two awards will be given, based on best mass of either gripper and lowest total cost.

## **Purchasing Procedure**

Your team will have a budget of \$250 to purchase materials, catalog components, and/or other products and services for your gripper. Please keep track of all spending as detailed below to ensure prompt ordering of your parts and reimbursements. You must purchase at least one shaft and bearing.

*Catalog Components:* For purchases from McMaster-Carr ([www.mcmaster.com](http://www.mcmaster.com)) and Stock Drive Products ([www.sdp-si.com](http://www.sdp-si.com)), we will handle your part orders using the following procedures. For McMaster-Carr parts, please first build an order online. Double check your quantities and that everything is in stock (“ships today/tomorrow”). Next, click “Forward” to email the order. In the body of the email, please note that this is a purchase for 24-370, Group #N. Email the order to [ginnyb@andrew.cmu.edu](mailto:ginnyb@andrew.cmu.edu), making sure to copy yourself. For components from Stock Drive, use the purchase request form found online. Between these two sources, you should be able to obtain sufficient components to construct your gripper. However, you may also use the procedures below.

*CMU Machine Shop:* Stock and other small items may be available for purchase from the machine shop. Jim Dillinger is in charge of such transactions and may be able to bill the course directly. If you give him sufficient lead time and have enough budget, the shop may even be able to machine some of your components. Jim may or may not be able to accommodate your group’s needs, so be sure to ask in advance. Keep a detailed record of all such purchases.

*All Other Purchases:* For orders from all other vendors, please use your own funds and save your receipts. Examples include local hardware stores, other online catalogs, and other custom machining or prototyping services. After completion of the project, one member of your team will file for reimbursement using the form provided.

## **Manufacturing Procedure**

Your team will be responsible for the fabrication of all custom components of your gripper. You may use the Mechanical Engineering machine shop during normal shop hours. Please be advised that other courses, such as machine shop practice, may have priority over some of the machines some of the time. Those team members who have completed 24-200 may use mills, lathes, drill presses, band saws, and other fabrication machines. Please ask Jim, Ed, or John if you are uncertain about any aspect of using these tools. All team members can use the laser cutter to fabricate parts. Please use the provided guidelines for operating the laser cutter. Only use the laser to cut the same type of Acrylic as was used in the first project, unless you have specific permission. Please see Ed with any questions about use of the laser cutter. Please keep in mind that other groups will also want to use the equipment towards the due date of your projects and plan your time accordingly.

In addition to the machine shop, you may also use the hand tools available in the workshop attached to the undergraduate lounge. To use hand drills, please see Ed or the TAs. This area is also an excellent place to store partially-completed grippers so that your team members can continue working in your absence. Please clear a space for your project on one of the shelves, being respectful of the other students’ work.

You must machine at least one component out of Aluminum or Steel. You must laser cut at least one component out of Acrylic.

## First Revision Report

Along with your first functional prototype, please submit a cover page (only) that adheres to the same format as the full report.

## Final Report

You will submit a final report presenting your final design, as well as the conceptualization, simple modeling, detailed modeling and analysis, and manufacturing that went into its creation. The report should be divided into the following sections:

1. Cover page: Please include the following on one side of one page:
  - a. Your group number, team member names, the project name, and the date
  - b. An isometric screen shot of your assembly at the top of the page
  - c. A brief description of the design and rationale, in 200 words or less.
  - d. Estimated peak force the gripper must apply to the sphere in the vertical direction,  $F_p$
  - e. Estimated overall factor of safety with respect to dropping the sphere,  $FOS_{grip}$
  - f. Estimated overall factor of safety with respect to part strength,  $FOS_{strength}$
  - g. Your guess at the weakest link, i.e. the place your design would fail if it did.
2. Conceptual Design Sketches
  - a. Please include all your notes and sketches from your idea generation sessions. These will be evaluated on the basis of apparent quality of design ideas. A typical set of sketches and notes might occupy 2 pages for each component in your assembly.
  - b. Your notes must include free-body diagrams, using force and moment balance to obtain reaction forces, with symbolic parameters. This will allow you to understand the implications of different design choices on the function of your components and assembly.
3. Simple Modeling of Candidate Designs
  - a. Please evaluate at least 2 candidate designs for each component using simple analytical modeling approaches
  - b. Include hand-drawn sketches of the simple models that allow analytical analyses of interest. Include the analysis you performed by hand. For example, you might model one aspect of the part as a beam in bending, and then relate peak stress, beam height, and part mass in a single function. You will probably need more than one simple model to analyze different aspects of each candidate model.
  - c. Although “conceptual design sketches” and “simple modeling of candidate designs” are listed as separate items, ideally these are intermingled in a logical way throughout your design sketches. There is a continuum between a stick figure on the back of an envelope and a Matlab parameter sweep, which you may find yourself flowing along as you design.
4. Materials Selection
  - a. On one page of your report, provide your rationale for your choice of materials. For each custom component you designed and built, explain your choice of material briefly (50 words or less). For example, you might say “The Connector plate was made from stainless steel because it is small and complex, has internal threads and was under high loads.”

5. Detailed Model and Analysis of Final Design
  - a. Please include model description for each of your custom-designed components. On a single page for each custom part, please include the following elements:
    - i. An isometric screen shot of the component
      1. On this screen shot, call out each feature and give a brief (~5 words) description of its function (this may be done by hand on the print-out).
    - ii. A screen shot of a static stress analysis for the component, with visible units in psi.
    - iii. The material used and the yield strength of the material
    - iv. The mass of the component
6. Component Selection
  - a. On a single page of your report, provide your rationale for component selection. For each catalog part you chose, briefly explain what factors influenced your decision (50 words or less). For example, you might say “We used bushings for the Finger Bearings because mass and size were critical in this location, while friction and slight misalignment were tolerable. The picked this bushing because it could withstand the peak pressure while being small relative to comparable bearings.”
  - b. Include a spreadsheet of all catalog parts, raw materials, and other items purchased for the project.
7. Manufacturing Report
  - a. Please include a *fully dimensioned* engineering drawing for each custom component, including tolerances where necessary. You may rely on standard tolerances for non-critical design elements, i.e. x.xxx implies  $\pm 0.005$ ", x.xx implies  $\pm 0.01$ ", and so on.
8. Self and Peer Evaluations
  - a. Each team member will complete the evaluation sheet in the appendix below. These will be turned in anonymously at the same time as the project reports.
9. Reimbursement
  - a. Include a single reimbursement form for all purchases your team made using personal funds. Remember that the University cannot reimburse taxes. A check will be mailed to the listed individual within one month.



**Self and Peer Evaluation Form**

Project 2, Engineering Design I, 24-370, Spring 2011

Please report on your teams division of labor and ease of collaboration below. Your anonymous comments will be summarized and given to team members if there is an opportunity for constructive criticism.

**Part 1: Self Evaluation**

Which custom components were you responsible for designing?

Which custom components were you responsible for fabricating?

As a percentage of the total effort required for all aspects of the project, what was your contribution? If all work were divided evenly, this would mean each team member contributed ~20%.

On a scale of 0-5, with 5 being best, how easy did you think it was for your peers to collaborate with you?

**Part 2: Peer Evaluation**

For each of your colleagues, please answer a subset of the same questions.

Name: % effort: Ease of collaboration (0-5):  
Constructive suggestions:

Name: % effort: Ease of collaboration (0-5):  
Constructive suggestions:

Name: % effort: Ease of collaboration (0-5):  
Constructive suggestions:

Name: % effort: Ease of collaboration (0-5):  
Constructive suggestions:

Name: % effort: Ease of collaboration (0-5):  
Constructive suggestions: